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(54) **CONTROL OF COMBUSTION REACTION PHYSICAL EXTENT**

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CPC ***F23C 99/001*** (2013.01); ***F23N 5/022*** (2013.01); ***F23N 5/082*** (2013.01); ***F23N 5/123*** (2013.01); ***F23N 5/203*** (2013.01); *F23N 2029/20* (2013.01)

(58) **Field of Classification Search**
CPC F23N 5/022; F23N 5/082; F23N 5/123; F23N 5/203; F23N 2029/20; F23C 99/001
See application file for complete search history.

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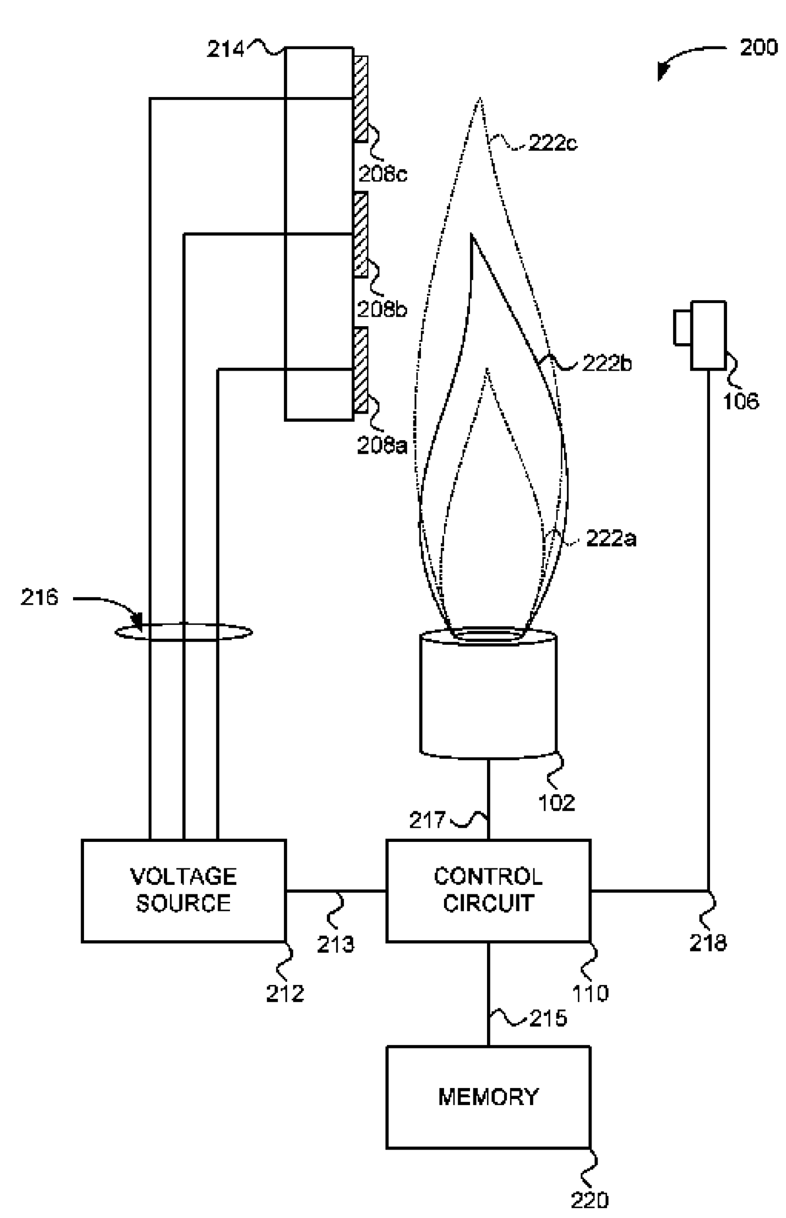
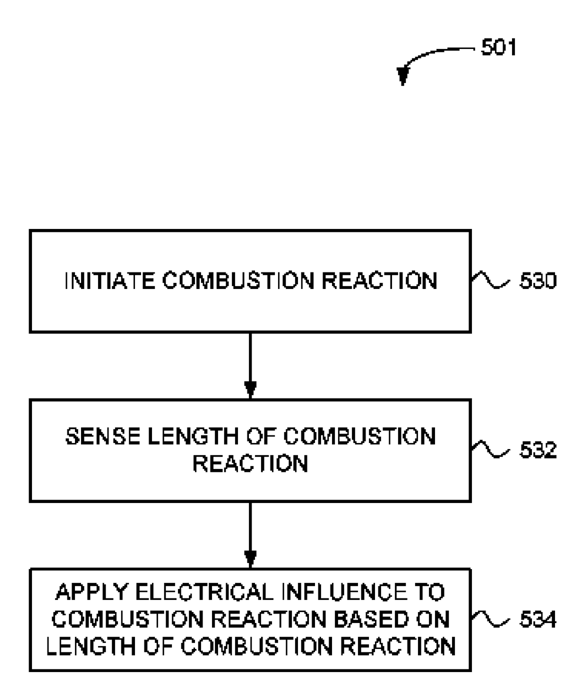
(57) **ABSTRACT**

Technologies are described for applying electrical energy according to a physical extent of a combustion reaction, which may include: supporting a combustion reaction at a fuel source; sensing a physical extent of the combustion reaction with respect to a plurality of different locations of a plurality of electrodes; and applying electrical energy to the combustion reaction via at least one of the plurality of electrodes responsive to the physical extent of the combustion reaction. Sensing the physical extent of the combustion reaction may include receiving a sensor signal corresponding to the physical extent of the combustion reaction.

38 Claims, 7 Drawing Sheets





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(51) **Int. Cl.**

F23N 5/08	(2006.01)
F23N 5/12	(2006.01)
F23N 5/20	(2006.01)

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FIG. 1

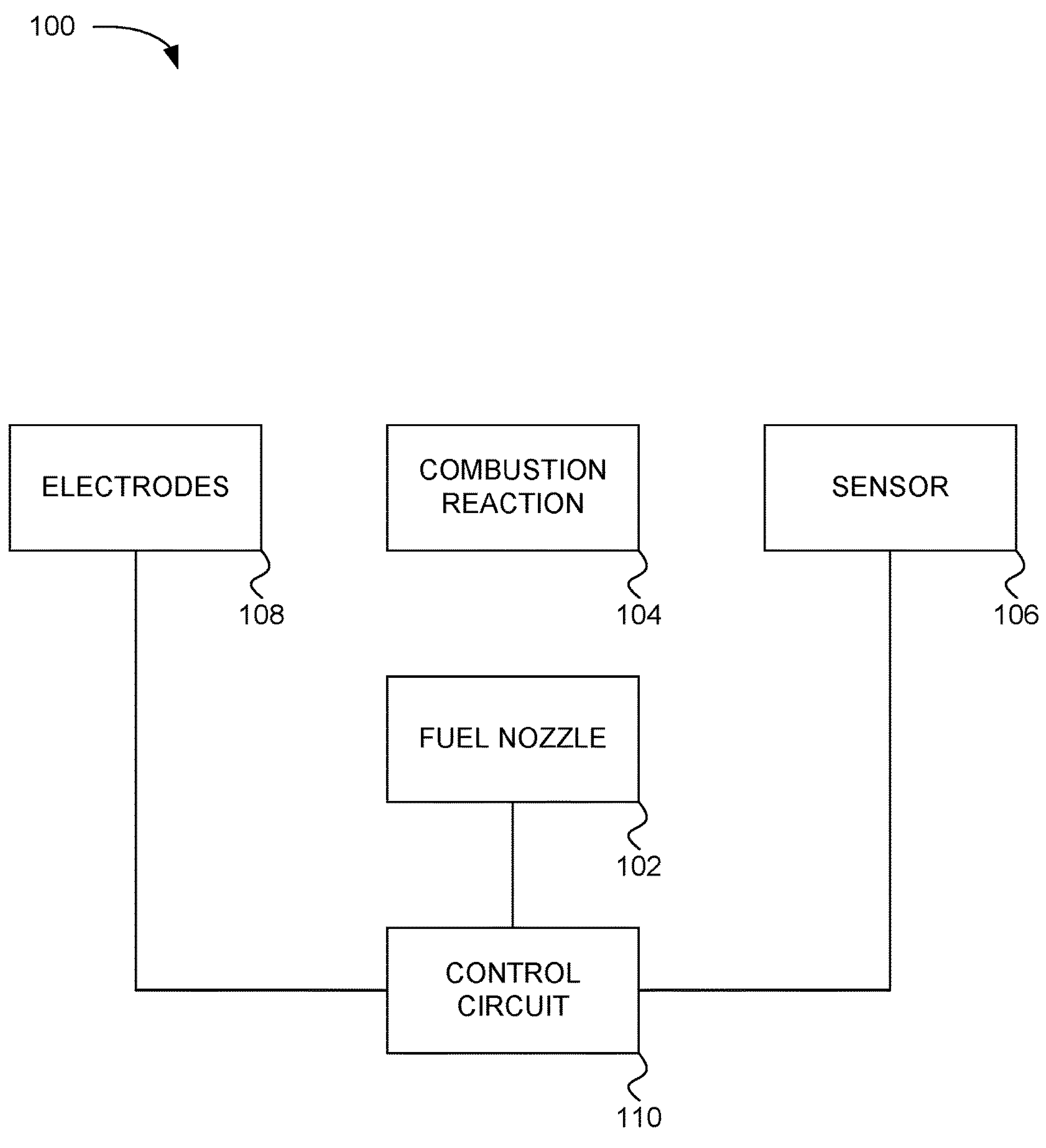

100
ELECTRODES
108
COMBUSTION REACTION
104
SENSOR
106
FUEL NOZZLE
102
CONTROL CIRCUIT
110

FIG. 2

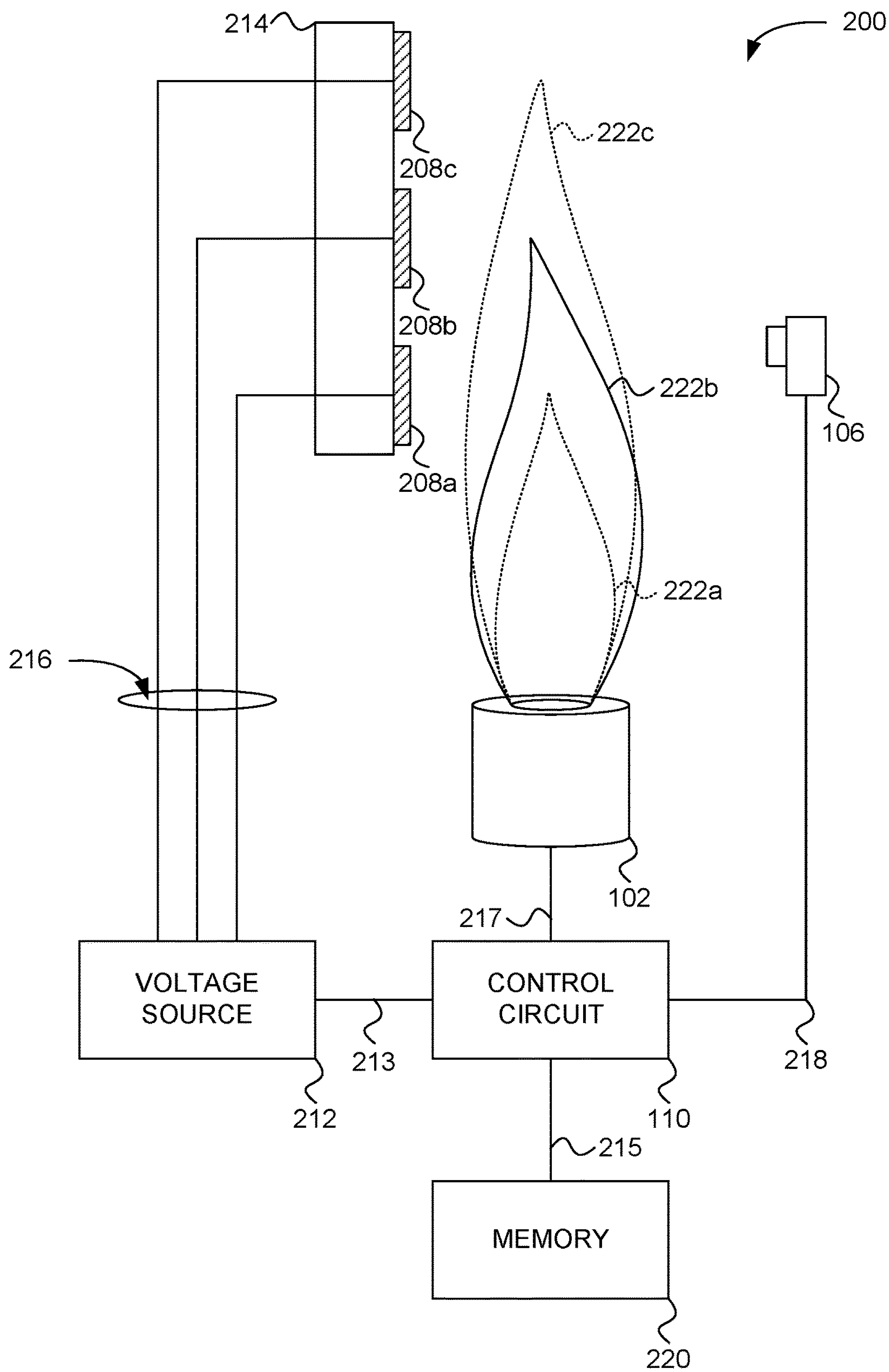

214
200
222c
208c
208b
222b
106
208a
222a
216
102
217
VOLTAGE SOURCE
CONTROL CIRCUIT
213
218
212
110
215
MEMORY
220

FIG. 3

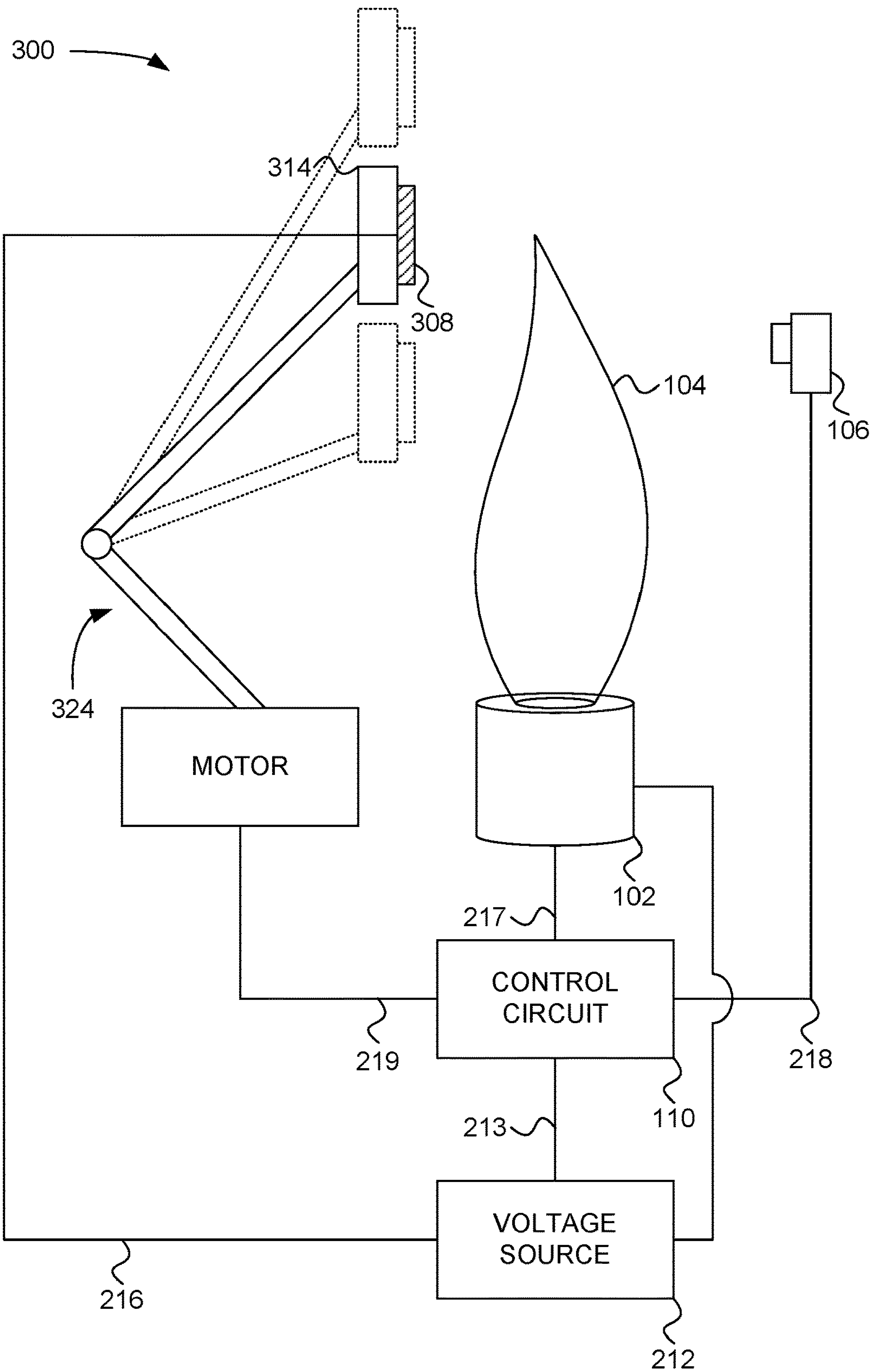

300
314
308
104
106
324
MOTOR
102
217
CONTROL
CIRCUIT
219
218
110
213
VOLTAGE
SOURCE
216
212

FIG. 4

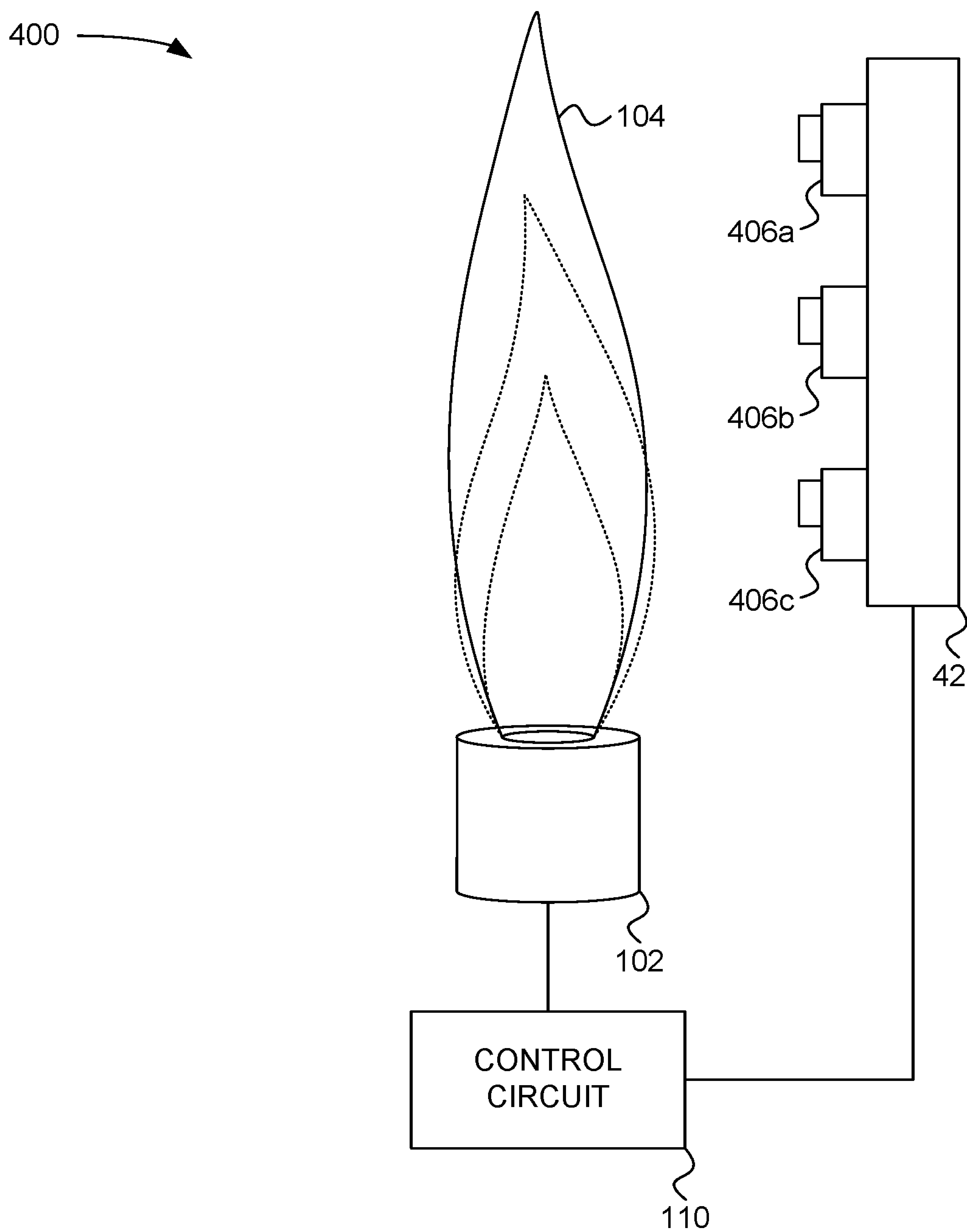


FIG. 5

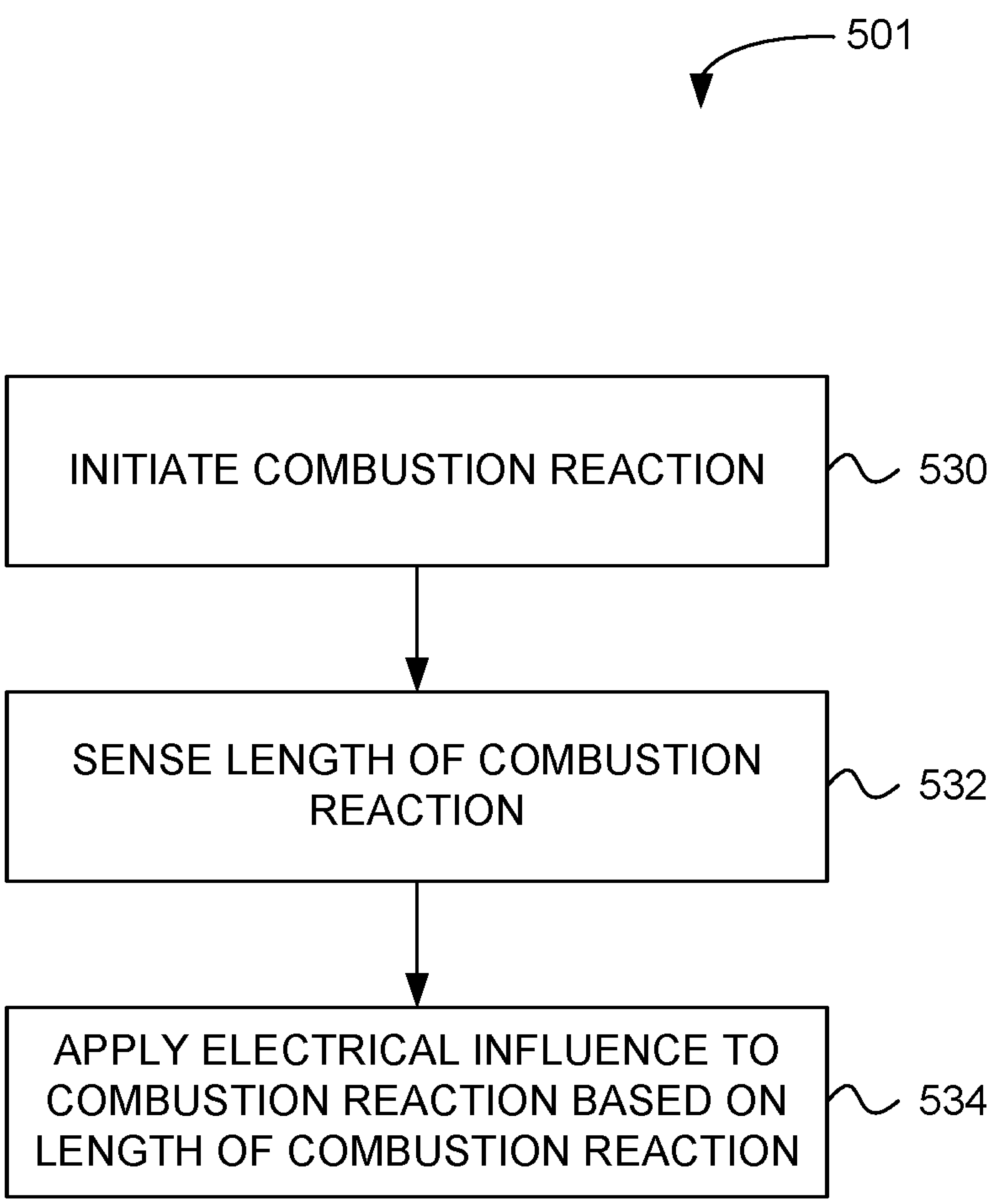

501
INITIATE COMBUSTION REACTION
530
SENSE LENGTH OF COMBUSTION REACTION
532
APPLY ELECTRICAL INFLUENCE TO COMBUSTION REACTION BASED ON LENGTH OF COMBUSTION REACTION
534

FIG. 6

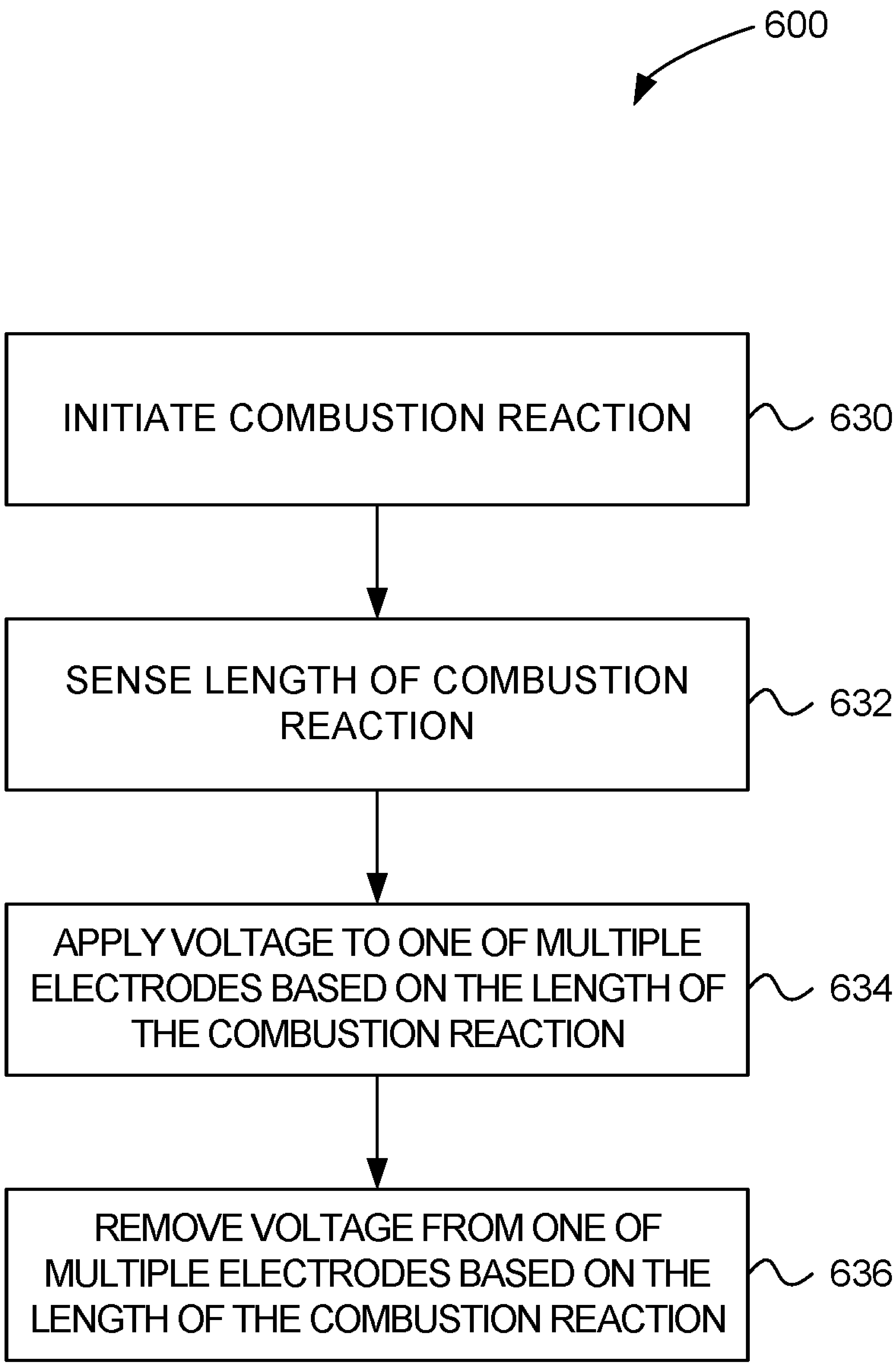
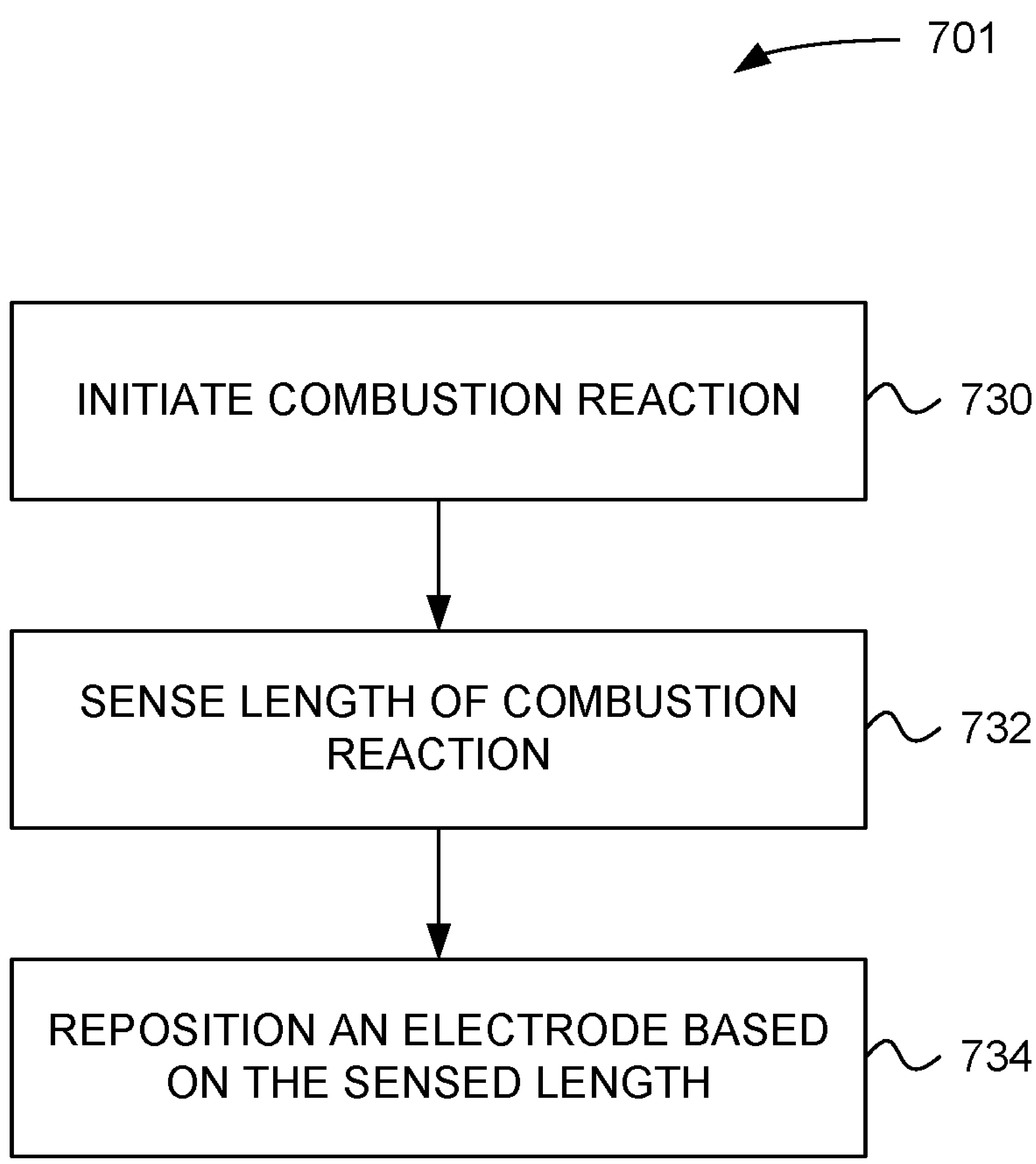

600
INITIATE COMBUSTION REACTION
630
SENSE LENGTH OF COMBUSTION REACTION
632
APPLY VOLTAGE TO ONE OF MULTIPLE ELECTRODES BASED ON THE LENGTH OF THE COMBUSTION REACTION
634
REMOVE VOLTAGE FROM ONE OF MULTIPLE ELECTRODES BASED ON THE LENGTH OF THE COMBUSTION REACTION
636

FIG. 7


701
INITIATE COMBUSTION REACTION
730
SENSE LENGTH OF COMBUSTION REACTION
732
REPOSITION AN ELECTRODE BASED ON THE SENSED LENGTH
734

CONTROL OF COMBUSTION REACTION PHYSICAL EXTENT

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a U.S. Continuation Application which claims priority benefit under 35 U.S.C. § 120 (pre-AIA) of co-pending International Patent Application No. PCT/US2014/056928, entitled "CONTROL OF COMBUSTION REACTION PHYSICAL EXTENT," filed Sep. 23, 2014; which application claims priority benefit U.S. Provisional Patent Application No. 61/881,420, entitled "CONTROL OF COMBUSTION REACTION PHYSICAL EXTENT," filed Sep. 23, 2013, each of which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

SUMMARY

One embodiment is a system configured to apply electrical energy to a combustion reaction responsive to or to control a physical extent of the combustion reaction. The system may include a plurality of electrodes configured to apply electrical energy to a combustion reaction at a fuel source. Each of the plurality of electrodes may have a location with respect to the combustion reaction. The system may include an electrical power supply including a plurality of outputs. Each of the plurality of electrodes may be operatively coupled to at least one of the plurality of outputs. The system may include a controller configured together with the electrical power supply and the plurality of electrodes to apply electrical energy to the combustion reaction. The controller may apply electrical energy to the combustion reaction responsive to a physical extent of the combustion reaction with respect to the location of at least one of the plurality of electrodes.

One embodiment is a method for applying electrical energy according to a physical extent of a combustion reaction. The method may include supporting a combustion reaction at a fuel source. The method may include sensing a physical extent of the combustion reaction with respect to a plurality of different locations of a plurality of electrodes. The method may include applying electrical energy to the combustion reaction via at least one of the plurality of electrodes responsive to the physical extent of the combustion reaction. Sensing the physical extent of the combustion reaction may include receiving a sensor signal corresponding to the physical extent of the combustion reaction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for applying electrical energy to a combustion reaction, according to one embodiment.

FIG. **2** is an illustration of a system including multiple electrodes for applying electrical energy to a combustion reaction, according to one embodiment.

FIG. **3** is an illustration of a system including a movable electrode for applying electrical energy to a combustion reaction, according to one embodiment.

FIG. **4** illustrates a system including a plurality of sensors for measuring the length of a combustion reaction, according to one embodiment.

FIG. **5** is a flow chart of a process for applying electrical energy to a flame, according to one embodiment.

FIG. **6** is a flowchart of a process for applying electrical energy from multiple electrodes to a combustion reaction, according to one embodiment.

FIG. **7** is a flowchart of a process for applying electrical energy from a movable electrode to a combustion reaction, according to one embodiment.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the disclosure.

FIG. **1** is a block diagram of a combustion system **100**, according to one embodiment. The combustion system **100** includes a fuel nozzle **102** configured to initiate and sustain a combustion reaction **104**. A sensor **106** is positioned adjacent to the combustion reactions **104**. A plurality of electrodes **108** are also positioned adjacent to the combustion reaction **104**. A control circuit **110** is coupled to the fuel nozzle **102** the sensor **106** and the electrodes **108**.

The fuel nozzle **102** is configured to output fuel for the combustion reaction **104** upon receiving a command from the control circuit **110**. Upon receiving the command from the control circuit **110**, the fuel nozzle **102** outputs fuel from the fuel nozzle **102** and ignites the fuel to initiate the combustion reaction **104**.

The fuel nozzle **102** can output both fuel and an oxygen source such as air into a combustion chamber in which the combustion reaction **104** takes place. Alternatively, the fuel nozzle **102** outputs only fuel while a separate nozzle outputs a source of oxygen for the combustion reaction **104**. The fuel nozzle **102** can include multiple nozzles that output fuel and multiple nozzles that output and oxygen source.

The electrodes **108** are positioned adjacent the combustion reaction **104**. In one embodiment, the combustion reaction **104** extends vertically and the electrodes **108** are each positioned a respective distance from the fuel nozzle in the vertical direction. The electrodes **108** can therefore be arranged in a vertical line adjacent to the combustion reaction. Alternatively, electrodes **108** can be positioned on different sides of the combustion reaction **104** and at different heights.

In one embodiment, the electrodes **108** can be separated laterally from the combustion reaction **104** by a small dielectric gap. In particular, a dielectric gas such as air or flue gas can separate the electrodes **108** from the combustion reaction **104**. Alternatively, one or more of the electrodes can be positioned within the combustion reaction **104**.

The electrodes **108** can each exert an electrical influence on the combustion reaction **104** in order to modify one or more parameters of the combustion reaction **104** such as flame length, flame temperature, flame color, the completeness of the combustion of the fuel, etc. For example, the control circuit **110** can apply respective voltages to the electrodes **108**. In this manner, one or more of the electrodes **108** can generate an electric field that will influence the combustion reaction **104**, can act as a source of charged particles for the flame, or can otherwise influence the combustion reaction **104**.

In order to enable increased precision in influencing the combustion reaction **104**, the sensor **106** is positioned adjacent to the combustion reaction **104**. In one embodiment, the sensor **106** senses the length of the combustion reaction **104** and transmits to the control circuit **110** a signal indicative of the length of the combustion reaction **104**. Alternatively, the sensor **106** can sense another parameter of the combustion reaction **104**.

When the control circuit **110** receives the signal from the sensor **106**, the control circuit **110** can adjust the respective voltages applied to the electrodes **108**. For example, if the sensor **106** indicates that the combustion reaction **104** is comparatively short in length, then the control circuit **102** can increase the voltage on one of the electrodes **108** closest to the combustion reaction **104**. At the same time, the control circuit **110** can reduce the magnitude of the voltage applied to one or more of the electrodes **108** that are further from the fuel nozzle **102** than the length of the combustion reaction. Alternatively, the control circuit **110** can completely remove respective voltages from one or more of the electrodes **108** most distant from the fuel nozzle **102**.

If the sensor **106** indicates that the combustion reaction **104** extends beyond one or more of the electrodes **108** closest to the fuel nozzle **102**, then the control circuit **110** can reduce the magnitude of respective voltages applied to one or more of the electrodes **108** closest to the fuel nozzle **102**. Control circuit **110** can also increase the magnitude of the voltage of one or more of the electrodes **108** that are near the end of the combustion reactions **104**.

In one embodiment, the control circuit **110** can apply respective voltages to one or more of the electrodes **108** that are near a center of the combustion reaction **104** as indicated by the sensor **106**. At the same time, the control circuit **110** can reduce or remove voltages applied to one or more of the electrodes **108** that are relatively far from a center of the combustion reaction **104**.

In one embodiment, the control circuit **110** can apply or increase the respective voltages to all the electrodes **108** that are within a distance from the fuel nozzle **102** corresponding to the length of the combustion reaction **104** or a selected portion of the length of the reaction **104**. The control circuit **110** can also reduce or remove respective voltages applied to those electrodes **108** that are further from the fuel nozzle **102** than the length of the combustion reaction **104**.

Electrodes **108** can also be used to help control the length of the combustion reaction **104**. For example by applying a high-voltage to a selected one or more of the electrodes **108**, the length of the combustion reaction **104** can be extended or reduced to a position corresponding to the selected one or more electrodes **108**.

In a particular application, it may be desirable that the combustion reaction **104** has a particular length. If the sensor **106** indicates that the length of the combustion reaction **104** is currently shorter than the desired length of the combustion reaction **104**, then the control circuit **110** can increase a magnitude of the voltage applied to one or more of the electrodes whose position corresponds to the desired reaction length in order to draw the combustion reaction **104** to the desired length. At the same time, the control circuit **12** can decrease a magnitude of the voltage applied to one or more the electrodes **108** whose position is near to the fuel nozzle **102** than the desired length of the combustion reaction **104**.

Alternatively, if the sensor **106** indicates that the length of the combustion reaction **104** is currently longer than the desired length of the combustion reaction **104**, then the control circuit **110** can increase a magnitude of the voltage applied to one or more of the electrodes **108** whose positions correspond to the desired length of the combustion reaction in order to draw the combustion reaction **104** down to the desired length. At the same time, the control circuit **110** can reduce the magnitude of the voltage applied to one or more of the electrodes **108** that are positioned further from the fuel nozzle **102** than the desired length of the combustion reaction **104**. The control circuit **110** can also apply a voltage of opposite polarity (with respect to the polarity of the voltage applied to those electrodes whose positions correspond to the desired length of the combustion reaction **104**) to those electrodes **108** whose positions are farther from the fuel nozzle **102** than the desired length of the combustion reaction **104** in order to shorten the combustion reaction **104** by repelling the combustion reaction **104** from those electrodes **108** whose position is farther from the fuel nozzle **102** than the desired length of the combustion reaction **104**.

While various examples have been given above regarding altering the respective voltages applied to the electrodes **108** based on the length of the combustion reaction **104**, those of skill in the art will recognize, in light of the present disclosure, that the respective voltages can be altered in many ways other than those described above in order to influence the combustion reaction **104**. Likewise, those of skill in the art will recognize that the control circuit **110** can alter the voltages applied to the electrodes **108** based on parameters other than the length of the combustion reaction **104**. All such other schemes for applying voltages to the electrodes **108** and all such other combustion reaction parameters based on which the control circuit **110** alters the voltages fall within the scope of the present disclosure.

In one embodiment, the system **100** includes an input terminal (not shown in FIG. **1**) coupled to the control circuit. An operator of the control system can view of the combustion reaction **104** and can adjust the respective voltages applied to the electrodes **108** in order to control the length or another parameter of the combustion reaction **104**. In one example, the combustion system **100** includes a window by which the user can see the combustion reaction **104**. Alternatively, the system **100** can include an image sensor and a display each coupled to the control circuit. The image sensor can capture an image or video of the combustion reaction **104** and then display can display the image or video of the combustion reaction **104**. The operator can view the image or video of the combustion reaction **104** on the display and can use the input terminal to manually adjust the voltages applied to the electrodes **108** in order to adjust the length or other parameter of the combustion reaction **104**.

FIG. **2** is an illustration of a combustion system **200**, according to one embodiment. The combustion system **200** includes a fuel nozzle **102** configured to sustain a combustion reaction **104**. A sensor **106** is positioned adjacent to the combustion reaction **104**. Three electrodes **208**A, **208**B, and **208**C are positioned adjacent the combustion reaction **104** opposite from the sensor **106** and fixed to a support **214**. Each of the electrodes **208**A-**208**C are connected to a voltage source **212** by wires **216**. The control circuit **110** is coupled to the voltage source **212** by one or more wires **213**, to the sensor **106** by one or more wires **218**, to the fuel nozzle **102** by one or more wires **217**, and to a memory **220** by one or more wires **215**.

In FIG. **2**, the combustion reaction **104** has a length corresponding to position **222**B. Some of the other possible lengths of the combustion reaction **104** correspond to positions **222**A and **222**C shown in dashed lines. Position **222**A corresponds generally to a vertical position of the electrode **208**A. Position **222**B corresponds generally to a vertical position of the electrode **208**B. Position **222**C corresponds generally to a vertical position of the electrode **208**C. The length of the combustion reaction **104** is not limited to those positions shown in FIG. **2**.

In one embodiment, the sensor **106** senses the length of the combustion reaction **104**. The sensor **106** then transmits a sensor signal to the control circuit **110** via the wire **218**. The sensor signal is indicative of the length of the combustion reaction **104**.

Upon receiving the sensor signal from the sensor **106**, the control circuit **110** can adjust the respective voltages applied to the electrodes **208**A-**208**C by the voltage source **212**. The control circuit **110** can adjust the voltages applied to the electrodes **208**A-**208**C in order to produce a desired characteristic in the combustion reaction **104**. In one embodiment, the control circuit **110** can adjust the voltages applied to the electrodes **208**A-**208**C to change the length of the combustion reaction **104** to a particular position. Alternatively, the control circuit **110** can adjust the voltages applied to the electrodes **208**A-**208**C in order to more effectively apply electrical influence to the combustion reaction **104** based on the detected length. The voltage source **212** can apply a voltage to the fuel nozzle **102** in order to impart a voltage to the combustion reaction **104**, thereby enabling the electrodes **208**A-C to influence the combustion reaction in a desired manner by application of selected voltages to the electrodes from the voltage source **212**.

In one embodiment, the control circuit **110** is configured to maintain the length of the combustion reaction **104** at a particular position selected by a user and/or stored in the memory **220**. In one example the control circuit **110** is configured to maintain a length of the combustion reaction **104** at a position corresponding to position **222**A. If the sensor signal indicates that the combustion reaction **104** has a length corresponding to position **222**B, than the control circuit **110** can increase a magnitude of the voltage applied to the electrode **208**A and decrease a magnitude of the voltages (or remove the voltage entirely) applied to the electrodes **208**B, **208**C. Alternatively, the control circuit **110** can apply to one or both of the electrodes **208**B, **208**C a voltage having a polarity opposite to that applied to the electrode **208**A in order to repel the combustion reaction **104** from the electrodes **208**B, **208**C thereby shortening the combustion reaction **104**.

In another example, the control circuit **110** is configured to maintain a length of the combustion reaction **104** at a position corresponding to position **222**B. If the sensor signal indicates that the combustion reaction **104** has a length corresponding to position **222**A or to position **222**C, then the control circuit **110** can increase a magnitude of the voltage applied to the electrode **208**B and decrease a magnitude of the voltages (or remove the voltages entirely) applied to the electrodes **208**A, **208**C.

In one embodiment, the control circuit **110** is configured to apply voltages to the electrodes **208**A-**208**C based on the detected length of the combustion reaction **104** in order to energize one or more of the electrodes **208**A-C having a position suitable to influence the combustion reaction **104**. For example, if the sensor signal indicates that the combustion reaction **104** extends to the position **222**C, the control circuit **110** can apply a voltage to the electrode **208**C in order to influence the combustion reaction **104**. Likewise, if the sensor signal indicates that the combustion reaction **104** extends to the position **222**A, the control circuit **110** can apply a voltage to the electrode **208**A in order to influence the combustion reaction **104**. The control circuit **110** can also reduce or disconnect voltages applied to electrodes that are not in a position to influence the combustion reaction **104** and a desired manner.

The respective voltages applied to the electrodes **208**A-C from the voltage source **212** can include DC voltages or periodic voltage waveforms such as sinusoidal voltages, sawtooth voltages, triangular voltages, square wave voltages etc. The periodic voltage waveforms may have a frequency between 50 and 1500 Hz. Additionally or alternatively, the frequency of the periodic waveforms may be between 200 and 800 Hz. The voltage source **212** may be configured to apply periodic voltage waveforms having peak-to-peak values between 1 kV and 80 kV.

In one embodiment, the sensor **106** may not be present. Instead, one or more of the electrodes **208**A-**208**C can act as a sensor in combination with the control circuit **110**. In particular, the control circuit **110** is configured to sense the length of the combustion reaction **104** based on a variation in electrical energy at the combustion reaction **104** via one or more of the electrodes **208**A-C. One or more of the plurality of electrodes **208**A-C may be configured as a corona electrode and the control circuit **110** may be further configured to sense the physical extent of the combustion reaction **104** according to a short at the corona electrode. The control circuit **110** may be further configured to de-energize the corona electrode responsive to the short at the corona electrode. One or more of the plurality of electrodes **208**A-C may be configured as a field electrode and the control circuit **110** may be further configured to detect a change in a back electromotive force at the field electrode. The control circuit **110** may be further configured to cause a change in electrical energy applied to the field electrode responsive to the back electromotive force at the field electrode. The control circuit **110** may be further configured to control the length of the combustion reaction via a feedback loop that takes into account changes in electrical energy applied to the field electrode and the back electromotive force at the field electrode.

In one embodiment, the plurality of electrodes **208**A-C may include the first electrode **208**A configured as a charge electrode. The first electrode **208**A may be configured as the charge electrode to impart a combustion reaction voltage or a combustion reaction voltage majority charge to the combustion reaction voltage. The plurality of electrodes **208**A-C may include at least one field electrode, e.g., the second electrode **208**B, located further from the fuel source compared to the electrode **208**A. The at least one field electrode may be configured to attract the combustion reaction **104** based on the respective voltages applied to the electrode **208**B and the combustion reaction **104**.

In one embodiment, the first electrode **208**A and the second electrode **208**B may be configured to cooperate to increase or decrease the physical extent of the combustion reaction **104**. The plurality of electrodes **208**A-C may include two or more of the field electrodes configured as a plurality of ladder electrodes. For example, the electrodes **208**B, **208**C may be configured as ladder electrodes located further from the fuel nozzle **102** than the electrode **208**A. The ladder electrodes **208**B, **208**C may be configured to increase or decrease the physical extent of the combustion reaction **104** to the positions **2228**, **222**C respectively.

In one embodiment, the voltage source **212** may be configured to apply a DC voltage or constant sign charges to the first electrode **208**A. The voltage source **212** may be configured to apply a time-varying voltage or time-varying charge signs to the electrode **208**A. The voltage source **212** may be configured to apply a periodic voltage waveform to the electrode **208**B. The periodic voltage waveform may have a frequency between 50 and 1500 Hz. Additionally or alternatively, the frequency of the periodic waveform may be between 200 and 800 Hz. The voltage source **212** may be configured to apply a periodic voltage waveform having a voltage between 1 kV and 80 kV to the electrode **208**A. The respective voltages applied to the electrodes **208**A-C can include DC voltages, periodic voltages such as sinusoidal voltages, sawtooth voltages, triangular voltages, square wave voltages etc. The periodic voltage waveform may have a frequency between 50 and 1500 Hz. Additionally or alternatively, the frequency of the periodic waveform may be between 200 and 800 Hz. The voltage source **212** may be configured to apply periodic voltage waveforms having peak-to-peak values between 1 kV and 80 kV.

In an embodiment, the voltage source **212** may be configured to apply a voltage waveform to the first electrode **208**A. The voltage waveform may include one or more of the following waveforms. The voltage waveform may include a sinusoidal waveform. The voltage waveform may include a square waveform. The voltage waveform may include a sawtooth waveform. The voltage waveform may include a triangular waveform. The voltage waveform may include a logarithmic waveform. The voltage waveform may include an exponential waveform. The voltage waveform may include a truncated waveform of any of the preceding waveforms. The voltage waveform may include a combination of any two or more of the preceding waveforms.

In an embodiment, the control circuit **110** may include a sensing circuit configured to sense current flow between the electrode **208**A and the field electrode **208**B. The control circuit **110** may include one or more of voltage control logic, waveform duty cycle logic, waveform shape logic, or waveform frequency logic operatively coupled to the sensing circuit and configured to control one or more of voltage, waveform duty cycle, waveform shape, or waveform frequency responsive to the sensed current flow.

In one embodiment, one or more of the plurality of electrodes **208**A-C may be operatively coupled to the fuel nozzle **102**.

While the foregoing description has described the application of voltages to the electrodes **208**A-C in order to impart electrical energy to the combustion reaction **104**, electrical energy may be applied in the form of a charge, voltage, or electric field.

FIG. **3** is an illustration of a combustion system of **300**, according to one embodiment. The combustion system **300** includes a fuel nozzle **102** configured to sustain a combustion reaction **104**. A sensor **106** is positioned adjacent to the combustion reaction **104**. A mobile electrode **308** is positioned adjacent to the combustion reaction **104** and fixed to a support **314**. The mobile electrode **308** is coupled to a voltage source **212** by one or more wires **216**. The support **314** is coupled to a motor **324**. A control circuit **110** is coupled to the voltage source **212** by one or more wires **213**, to the sensor **106** by one or more wires **218**, to the fuel nozzle **102** by one or more wires **217**, and to the motor **324** by one or more wires **219**.

The sensor **106** measures a length of the combustion reaction **104** and transmits a sensor signal to the control circuit **110**. The sensor signal is indicative of the length of the combustion reaction **104**.

The control circuit **110** is configured to adjust a position of the electrode **308** in order to enable the electrode **308** to exert an electrical influence on the combustion reaction **104**. In particular, the control circuit **110** receives the sensor signal from the sensor **106**. The control circuit **110** computes a current length of the combustion reaction **104** based on the sensor signal. Based on the current length of the combustion reaction, the control circuit **110** adjusts the position of the electrode **308** by sending a control signal to the motor **324**. Upon receiving the control signal, the motor **324** adjust the position of the electrode **308** so that electrode **308** can exert a desired influence on the combustion reaction **104**. The control circuit **110** also controls the voltage source **212** to apply a voltage to the electrode **308** by which the electrode can influence the combustion reaction **104**.

In one example, the sensor **106** detects that the length of the combustion reaction **104** is shorter than a vertical distance between the fuel nozzle **102** and the electrode **308**. In response, the control circuit **110** causes the motor **324** to lower the electrode **308** to a position closer to the combustion reaction **104**. Alternatively, if the sensor **106** detects that the combustion reaction **104** extends beyond current position of the electrode **308**, then the control circuit **110** can cause the motor to raise the electrode **308** to a position adjacent to a particular portion of the combustion reaction **104**. Upon adjusting the position of the electrode **308**, the control circuit **110** can also cause the voltage source **212** to apply (or maintain) a particular voltage to the electrode **308** in order to electrically influence the combustion reaction **104**.

In one embodiment, the control circuit **110** can adjust the position of and the voltage on the electrode **308** in order to control the length of the combustion reaction **104**. For example, the control circuit **110** can be configured to maintain a selected length of the combustion reaction **104**. In order to cause the combustion reaction **104** to have the selected length, the control circuit **110** can adjust the position of the electrode **308** to correspond to the selected length of the combustion reaction **104**. The control circuit **110** can then cause the voltage source to 12 to apply a particular voltage to the electrode **308**. The combustion reaction **104** is thus drawn to a length corresponding to the position of the electrode **308**. In this manner, the control circuit **110** can increase or decrease the length of the combustion reaction according to instructions stored in the memory or input by an operator of the combustion system **300**.

In one embodiment, the fuel nozzle **102** is electrically conductive. In order to facilitate controlling a characteristic of the combustion reaction **104**, the voltage source **212** can apply a selected voltage to the fuel nozzle **102**, thereby imparting the selected voltage to the combustion reaction **104**. The respective voltages between the combustion reaction **104** and the electrode **308** allow the control circuit to control the combustion reaction **104** the desired manner.

FIG. **4** is a diagram of a combustion system **400**, according to one embodiment. The combustion system **400** includes a fuel nozzle **102** configured to maintain a combustion reaction **104**. A plurality of sensors **406**A-C are coupled to a sensor support **428**. A control circuit **110** is coupled to the fuel nozzle **102** and the sensors **406**A-C. Though not shown in FIG. **4**, the combustion system **400** can also include electrodes configured to exert electrical influence on the combustion reaction **104** as described above.

In one embodiment, the sensors **406**A-C continuously or periodically measure the length of the combustion reaction **104** and transmit a sensor signal, or a plurality of sensor signals, to the control circuit **110**. The sensor signal is indicative of the length of the combustion reaction **104**.

The sensors **406**A-C are collectively configured to measure the length of the combustion reaction **104**. The presence of multiple sensors **406**A-C can allow for a more accurate measurements of the length of the combustion reaction **104**. This is because the sensors **406**A-C are arranged at different vertical distances from the fuel nozzle **102** and therefore can make measurements at different distances from the fuel nozzle **102**.

The sensors **406**A-C can be temperature sensors, light sensors, infrared sensors, ultraviolet sensors, capacitive sensors, or any other sensors suitable to measure a length of the combustion reaction **104**.

As described previously, the control circuit **110** receives the sensor signal and controls one or more electrodes to exert a selected influence over the combustion reaction **104**.

FIG. **5** is a flow diagram of a process **501** for operating a combustion system, according to one embodiment. At **530**, a combustion reaction is initiated and maintained. This can include emitting fuel from a fuel nozzle and combusting the fuel with oxygen from an oxygen source. Alternatively, solid fuel can be used for the combustion reaction.

At **532** a sensor senses the length of the combustion reaction. The sensor can then transmit a signal to the control circuit indicating the length of the combustion reaction. The length of the combustion reaction can correspond to a distance from a fuel source to an end of the combustion reaction.

At **534**, the control circuit can cause an electrode to apply electrical influence to the combustion reaction based on the length of the combustion reaction. For example, the combustion reaction can energize an electrode whose position corresponds to the position of the combustion reaction in response to receiving the signal from the sensor. The control circuit can also de-energize one or more other electrodes not in a position to influence the combustion reaction in the selected manner. In this way, the combustion reaction can be controlled to have particular characteristics such as a particular length, a particular temperature, a particular color, or to achieve a more complete combustion of the fuel.

FIG. **6** is a flow diagram of a process **601** for operating a combustion system, according to one embodiment. At **630**, a combustion reaction is initiated and maintained. This can include emitting fuel from a fuel nozzle and combusting the fuel with oxygen from an oxygen source. Alternatively, solid fuel can be used for the combustion reaction.

At **632** a sensor senses the length of the combustion reaction. The sensor can then transmit a signal to the control circuit indicating the length of the combustion reaction. The length of the combustion reaction can correspond to a distance from a fuel source to an end of the combustion reaction.

At **634**, the control circuit can apply voltage to one or more of a plurality of electrodes adjacent the combustion reaction. For example, the combustion reaction can apply selected voltage to one or more of the plurality of electrodes whose positions correspond to the position of the combustion reaction in response to receiving the signal from the sensor.

At **636**, the control circuit can reduce or remove a voltage from one or more of the electrodes not in a position to influence the combustion reaction in the selected manner. In this way, the combustion reaction can be controlled to have particular characteristics such as a particular length, a particular temperature, a particular color, or to achieve a more complete combustion of the fuel.

FIG. **7** is a flow diagram of a process **701** for operating a combustion system, according to one embodiment. At **730**, a combustion reaction is initiated and maintained. This can include emitting fuel from a fuel nozzle and combusting the fuel with oxygen from an oxygen source. Alternatively, solid fuel can be used for the combustion reaction.

At **732** a sensor senses the length of the combustion reaction. The sensor can then transmit a signal to the control circuit indicating the length of the combustion reaction. The length of the combustion reaction can correspond to a distance from a fuel source to an end of the combustion reaction.

At **734**, the control circuit repositions an electrode to a position selected according to the measured length of the combustion reaction. The control circuit can then apply a voltage or other electrical signal to the electrode in order to electrically influence the combustion reaction in a selected manner.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

What is claimed is:

1. A system comprising:

a fuel nozzle configured to output fuel for a combustion reaction;

a first electrode positioned adjacent the fuel nozzle;

a second electrode positioned adjacent the first electrode;

a control circuit configured to apply a first voltage signal to the first electrode and a second voltage signal to the second electrode; and

a sensor positioned adjacent the fuel nozzle and configured to sense a length of the combustion reaction and to output a sensor signal indicative of the length, wherein the control circuit is configured to receive the sensor signal from the sensor and to apply, based on the sensor signal, the first voltage signal to the first electrode and the second voltage signal to the second electrode.

2. The system of claim **1**, wherein the first electrode is closer to the fuel nozzle than the second electrode.

3. The system of claim **2**, wherein the control circuit increases a magnitude of the second voltage signal if the sensor signal indicates that the combustion reaction extends beyond the first electrode.

4. The system of claim **3**, wherein the control circuit removes the first voltage signal from the first electrode if the sensor signal indicates the combustion reaction extends beyond the first electrode.

5. The system of claim **3**, wherein the control circuit decreases a magnitude of the first voltage signal if the sensor signal indicates that the combustion reaction extends beyond the second electrode.

6. The system of claim **2**, wherein the control circuit increases a magnitude of the first voltage signal, and decreases a magnitude of the second voltage signal, if the sensor signal indicates that the length of the flame no longer extends beyond the first electrode.

7. The system of claim **1**, comprising a memory coupled to the control circuit.

8. The system of claim **7**, wherein the control circuit is configured to receive the sensor signal, to compare the sensor signal to data stored in the memory, and to alter the first and second voltage signals based on the comparison of the sensor signal and the data stored in the memory.

9. The system of claim **8**, wherein the control circuit is configured to execute an algorithm stored in the memory and to alter the first and second voltage signals based on a result of the algorithm.

10. The system of claim **1**, comprising a voltage supply coupled to the control circuit and the first and second electrodes, wherein the control circuit is configured to apply the first and second voltage signals by controlling the voltage supply.

11. The system of claim **1**, wherein the control circuit is configured to cause the combustion reaction to extend to a position corresponding to the first electrode by applying the first voltage signal to the first electrode.

12. The system of claim **11**, wherein the control circuit is configured to cause the combustion reaction to extend to a position corresponding to the second electrode by applying the second voltage signal to the second electrode.

13. The system of claim **1**, wherein the control circuit is configured to apply a third voltage signal to the fuel nozzle.

14. The system of claim **13**, wherein the third voltage signal is ground.

15. The system of claim **1**, wherein the first voltage signal is a periodic voltage signal.

16. The system of claim **15**, wherein the second voltage signal is a periodic voltage signal.

17. The system of claim **15**, wherein the first voltage signal has a frequency between 50 and 1500 Hz.

18. The system of claim **15**, wherein the first voltage signal has a peak-to-peak magnitude between 1 kV and 80 kV.

19. The system of claim **1**, comprising an electrode support structure positioned adjacent the fuel nozzle, the first and second electrodes being positioned on the electrode support structure.

20. The system of claim **1**, comprising a third electrode positioned adjacent the second electrode and farther from the fuel nozzle than the second electrode, the second electrode being positioned farther from the fuel nozzle than the first electrode.

21. The system of claim **1**, wherein the control circuit is configured to receive input from an operator of the system and to adjust the first and the second voltage signals based on the input received from the first and second voltage signals.

22. The system of claim **21**, comprising an input terminal coupled to the control circuit, the input terminal configured to receive input from the operator and to pass the input to the control circuit.

23. The system of claim **21** comprising:

an image sensor coupled to the control circuit and configured to capture an image of the combustion reaction; and

a display coupled to the control circuit and configured to display the image of the combustion reaction.

24. A method comprising:

emitting fuel from a fuel nozzle;

sustaining a combustion reaction of the fuel;

applying a first voltage signal to a first electrode positioned adjacent to the combustion reaction;

applying a second voltage signal to a second electrode positioned adjacent to the combustion reaction;

altering the first and second voltage signals based on a parameter of the combustion reaction; and

sensing a length of the combustion reaction with a sensor positioned adjacent to the combustion reaction.

25. The method of claim **24** comprising:

passing a sensor signal from the sensor to a control circuit coupled to the sensor and to the first and second electrodes, the sensor signal being indicative of the length of the combustion reaction; and

applying or altering the first and second voltage signals by passing a control signal from the control circuit to a high voltage source coupled to the first and second electrodes.

26. The method of claim **25**, wherein the second electrode is closer to the fuel nozzle than the first electrode.

27. The method of claim **26**, comprising reducing a magnitude or removing the first voltage signal if the sensor signal indicates that the combustion reaction does not extend beyond the first electrode.

28. The method of claim **26**, comprising applying the second voltage signal if the sensor signal indicates that the combustion reaction does not extend beyond the first electrode.

29. The method of claim **25**, wherein the first electrode is closer to the fuel nozzle than the second electrode.

30. The method of claim **29**, comprising reducing a magnitude or removing the first voltage signal if the sensor signal indicates that the combustion reaction extends beyond the first electrode.

31. The method of claim **29**, comprising applying the second voltage signal if the sensor signal indicates that the combustion reaction extends beyond the first electrode.

32. The method of claim **24**, comprising causing the combustion reaction to extend to a position corresponding to the first electrode by applying the first voltage signal to the first electrode.

33. The method of claim **32**, comprising causing the combustion reaction to extend to a position corresponding to the second electrode by applying the second voltage signal to the second electrode.

34. The method of claim **24**, comprising applying a third voltage signal to the fuel nozzle.

35. The method of claim **34**, wherein the third voltage signal is ground.

36. The method of claim **24**, comprising positioning an electrode support structure adjacent the fuel nozzle, the first and second electrodes being fixed to the electrode support structure.

37. The method of claim **24**, comprising separating the first and second electrodes from the combustion reaction by a dielectric gap.

38. The method of claim **24**, comprising adjusting the first and second voltage signals based on input received from a user.

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